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PROJECT APOLLO

APOLLO-SATURN I LAUNCH PROBABILITY BASED ON WINDS ALOFT

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
Houston, Texas

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By Donald C. Wade

1.0 SUMMARY

Monthly launch probabilities based on wind data from the Cape Canaveral area are derived and presented for the SA-6 vehicle. Curves are also given for determining the monthly launch probabilities from this site for later Saturn I vehicles with different launch wind limitations.

2.0 INTRODUCTION

For scheduling and flight planning it is desirable to have some idea of the percentage of time a launch can be expected to be successful during a particular time period. This is a complex problem. One of the large unknowns in this problem is the effect of winds aloft on the vehicle. The object of this paper is to derive and present the launch probabilities, based on wind data, for the SA-6, and other Saturn I vehicles launched from Cape Canaveral, Florida. These probabilities are based on a seven-year survey of the winds at Cape Canaveral and Partick AFB. (These stations are only about 24 km apart). (Ref. 1)

The vehicle response was calculated by the method derived in reference 2. The monthly distribution of wind speeds used can be found in reference 3.

3.0 ASSUMPTIONS AND PROCEDURE

Listed below are the important assumptions utilized in this paper and its references:

1. The statistical wind data is representative of any future year (or month) of interest.

2. Windspeeds in the vicinity of a cumulative percentage frequency of 50 percent will be most frequently encountered.

3. Winds all blow in the same direction and are in the pitch plane of the vehicle.

4. Deviations from the programed attitude history are negligible. (Ref. 2)

5. The small angle approximation is valid when using angle of attack or engine deflection angle. (Ref. 2)

6. The wind does not affect the dynamic pressure significantly. (Ref. 2)

The procedure used in this study will now be described. The first step was to arrive at a wind profile for each month. The figures chosen were for the cumulative percentage frequency of 50 percent, as found in reference 1. These numbers represent the median values of wind speed which will not be exceeded by one-half of all occurrences (based on the period 1951 - 1957). It was assumed that these monthly wind speeds would be the ones most likely to be found during any particular month in the future. Note that this is an occurrence median rather than a magnitude mean. These profiles are plotted on figure 1.

The next step taken was to normalize these wind profiles. This was done by plotting the ratio of the windspeed to the peak windspeed (in the 30,000 to 45,000 foot altitude region) versus altitude (fig. 2). These curves suggest the possibility of using one normalized shape to represent all of them. This is an especially good approximation for the months with the stronger winds (winter months). The less critical months (summer months) do depart somewhat from this idea at higher and lower altitudes. (See fig. 2) These deviations however will not affect the answer appreciably in the area of maximum vehicle loads, that is, the 30,000 to 45,000 foot altitude range. Therefore one normalized shape was chosen which was representative of the stronger wind values. This non-dimensional wind shape is presented in figure 3. Four wind profiles were calculated from this shape and are shown on figure 4; these profiles simulate the profiles for the months of March, August, October and a profile with a 300 fps peak windspeed.

Next the effect of these wind profiles on the C-1 vehicle loads is studied. This is accomplished by the method of reference 2. The use of this method is best illustrated by an example. For the month of March the peak wind speed = 139.77 fps. Using this number and the normalized shape in Figure 3, the following values may be calculated:

Altitude Layer 1,000 ft.	V_n/V_{Peak} at mid-layer (Fig. 3)	V_{Peak} fps	V_n fps	$\frac{V_n - V_{(n-1)}}{10}$ fps
0 - 5	.15	139.77	20.97	2.10
5 - 10	.22	139.77	30.75	.98
10 - 15	.30	139.77	41.93	1.12
etc.				

Now having the simulated wind profile, the angle of attack due to the wind (α_w) may be calculated as follows (Reference 2):

$$\begin{vmatrix} a_{11} & & \\ a_{21} & a_{22} & \\ a_{31} & a_{32} & a_{33} \end{vmatrix} \begin{vmatrix} \frac{V_1}{10} \\ \frac{V_2 - V_1}{10} \\ \frac{V_3 - V_2}{10} \end{vmatrix} = \begin{vmatrix} \alpha_{w_1} \\ \alpha_{w_2} \\ \alpha_{w_3} \end{vmatrix}$$

where "a_{32}" is "a" from row 3, column 2 in Table 1. Physically this means it is the angle of attack response at the 3rd layer (12,500 ft.) due to a unit 10 fps wind starting at the 2nd layer (5,000 ft.).

Substituting numbers into the matrix equation yields:

$$\begin{vmatrix} 1.537 & & \\ .543 & .885 & \\ .255 & .430 & .650 \end{vmatrix} \begin{vmatrix} 2.10 \\ .98 \\ 1.12 \end{vmatrix}$$

$$= \alpha_{w_{0\ -5}} = 1.537\ (2.10) = 3.23$$

$$\alpha_{w_{5\ -10}} = .543\ (2.10) + .885\ (.98) = 2.01$$

$$\alpha_{w_{10\ -15}} = .255\ (2.10) + .430\ (.98) + .650\ (1.12) = 1.69$$

The programed angle of attack (α_p) must be added to these. The resulting angle of attack (α) may then be multiplied by the appropriate dynamic pressure (q). For the C-1 these values for αq become:

Altitude Layer 1,000 ft.	α_w Deg	Programed α_p Deg	$\alpha = \alpha_p + \alpha_w$ Deg	Dynamic Press. q psf	αq Deg-psf
0 - 5	3.23	.80	4.03	78	314
5 - 10	2.01	.50	2.51	244	612
10 - 15	1.69	.20	1.89	392	741

Thus αq may be calculated for altitudes from 0 to 70,000 feet using these data. Values have been calculated for the Saturn I vehicle and are plotted in Figure 5 as a function of altitude. The αq at the peak windspeed has been plotted as a function of the peak windspeed in Figure 6 from Figures 4 and 5.

Finally the monthly windspeed probabilities for Cape Canaveral are plotted in Figure 7 from data contained in Reference 3. For SA-6 the αq = 3,700 deg - psf (Reference: Memorandum for Chief, Spacecraft Technology Division from L. G. St. Leger dated November 19, 1962). In this study an allowance of 1,700 deg - psf is made for gusts, thus reducing the limit αq to 2,000 deg - psf. Entering Figure 6 with αq to 2,000 deg - psf yields a peak windspeed of 40 M/sec. Now entering Figure 7 with 40 M/sec, the monthly launch probabilities from Cape Canaveral may be obtained for the SA-6. These probabilities are listed in Table 2. Figure 6 and 7 permit the estimation of Saturn I launch probabilities from this site for peak αq's up to 4,150 deg - psf which corresponds to a peak windspeed of 100 M/sec.

4.0 RESULTS AND DISCUSSION

Table 2 and Figures 6 and 7 represent the results of this paper. Table 2 presents monthly launch probabilities of the SA-6 from Cape Canaveral, Florida. Figures 6 and 7 give the capability of obtaining this same information for other loading limitations of the Saturn I Vehicle launched from this location. These two figures are generally used in this fashion: The limiting αq is known or estimated; with this value Figure 6 is used to obtain the maximum permissible windspeed in the 30,000 to 45,000 foot altitude region. By entering Figure 7 with this windspeed, the monthly launch probabilities may be read directly.

The wind profile during any particular launch might be quite different from the value used in this study. It is not the intent of this paper to evaluate individual wind profiles however, but rather to give launch probabilities for future flights.

Windspeeds with a cumulative percentage frequency of 50% (median values) were assumed to be the most frequently encountered values. The normalized shape obtained from these values compares well with the normalized shapes for all the other percentage frequency levels.

The winds were assumed to be in the pitch plane of the vehicle and to blow in the same direction. The vehicles are launched essentially east. The winds are generally in the east-west plane with the exception of June and sometimes September. The winds speeds for these months are low however. The directions are essentially constant with increasing altitude, but there is a general tendency for a slight clockwise change.

5.0 REFERENCES

1. Smith, J. W., and Vaughan, W. W.: Monthly and Annual Wind Distribution as a Function of Altitude for Patrick Air Force Base, Cape Canaveral, Florida. NASA Huntsville, 1961.

2. Wade, D. C.: (Conf) Project Apollo An Approximate Method of Calculating the Angle of Attack Response of the C-1 Vehicle Due to Winds Measured Prior to Launch (U) title, NASA Houston, 1963.

3. Scoggins, J. R., and Vaughan, W. W.: Cape Canaveral Wind and Shear Data (1 thru 80 KM) For Use in Vehicle Design and Performance Studies. (Review Copy) NASA Hunstville, 1962.

6.0 TABLES

TABLE 1.- WIND RESPONSE MATRIX

Altitude - 1,000 ft.

Altitude Layer - 1,000 ft.	0	5	10	15	20	25	30	35	40	45	50	55	60	65
0 - 5	1.537													
5 - 10	.543	.885												
10 - 15	.255	.430	.650											
15 - 20	.138	.237	.363	.521										
20 - 25	.079	.146	.220	.321	.442									
25 - 30	.050	.092	.140	.201	.282	.381								
30 - 35	.030	.058	.093	.132	.192	.252	.342							
35 - 40	.020	.039	.060	.096	.140	.182	.242	.300						
40 - 45	.010	.025	.042	.070	.102	.133	.173	.222	.271					
45 - 50	.004	.018	.031	.049	.079	.100	.135	.170	.207	.250				
50 - 55	.002	.014	.025	.035	.060	.077	.105	.131	.161	.195	.221			
55 - 60	.000	.010	.020	.027	.048	.059	.084	.108	.132	.157	.180	.200		
60 - 65	.000	.008	.013	.022	.038	.050	.070	.087	.109	.130	.149	.165	.182	
65 - 70	.000	.004	.010	.030	.030	.041	.058	.071	.090	.108	.124	.139	.152	.163

TABLE II.- LAUNCH PROBABILITIES FOR SA-6

Month	% Time Limit αq = 2,000 deg-psf is Not Exceeded
Jan.	58.0
Feb.	53.0
Mar.	47.0
Apr.	64.0
May	85.0
June	96.5
July	99.8
Aug.	99.8
Sept.	99.8
Oct.	84.0
Nov.	62.0
Dec.	59.0

7.0 FIGURES

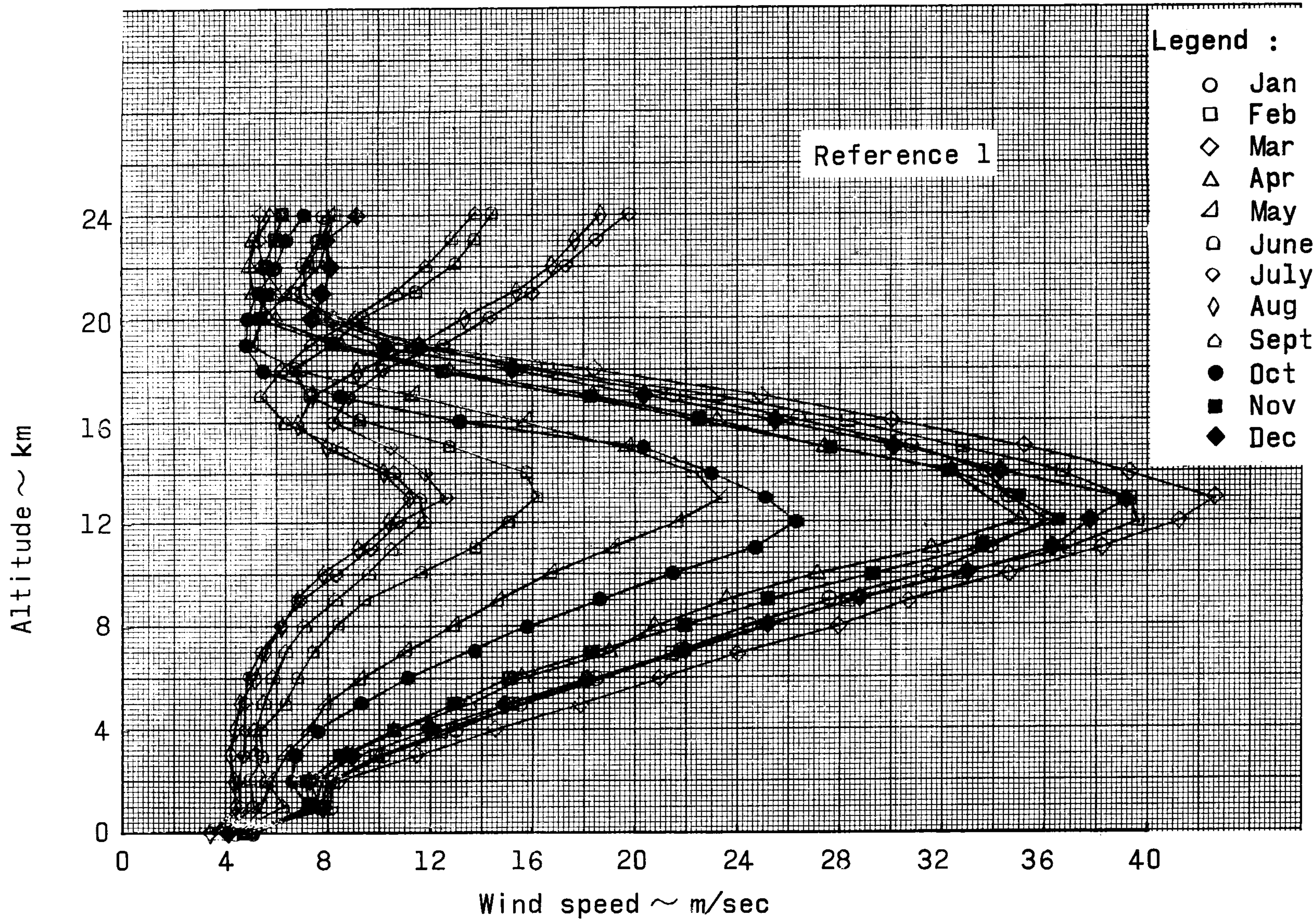

Figure 1.- Scalar wind distribution as a function of altitude for Cape Canaveral.

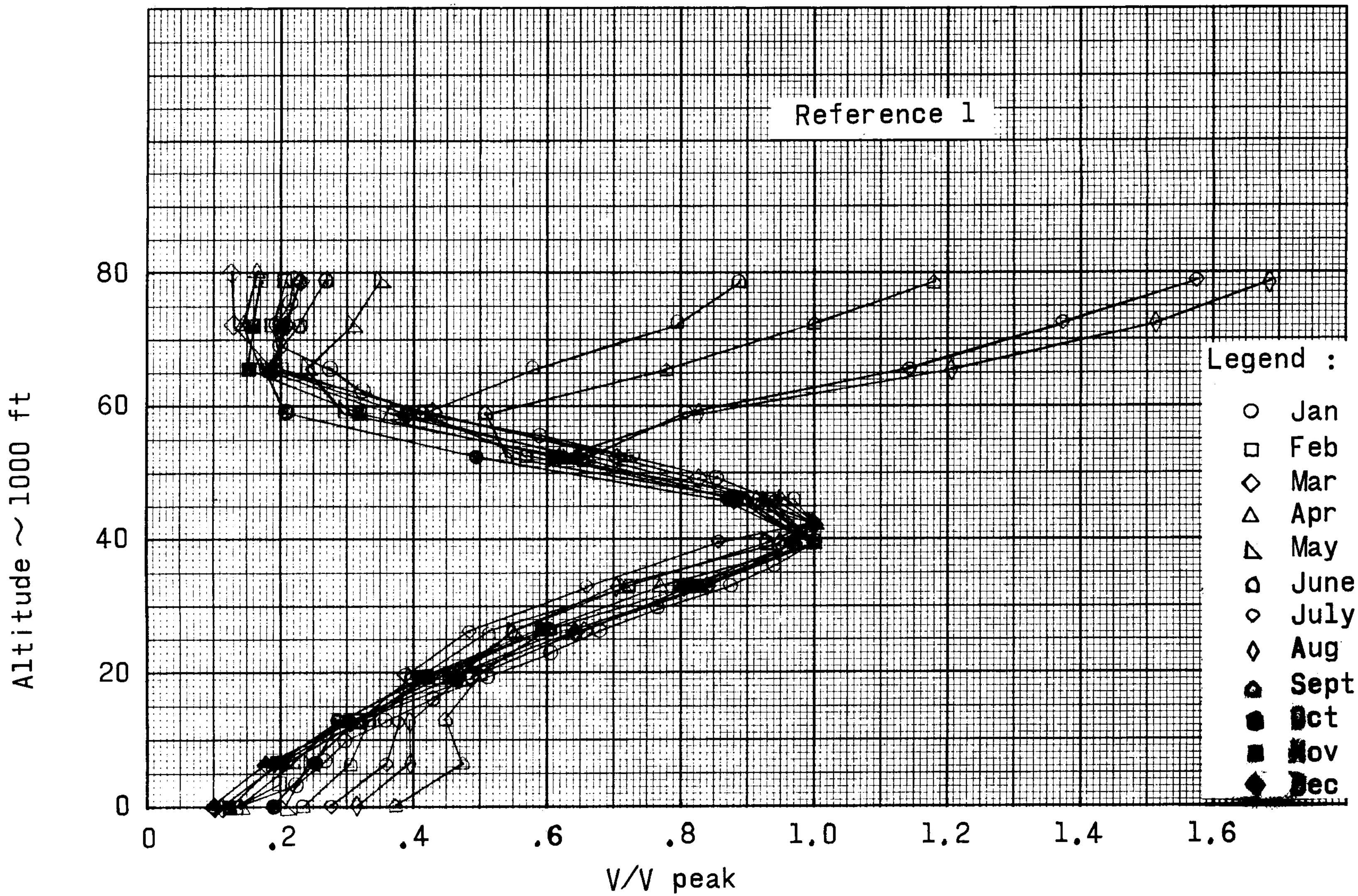

Figure 2.- Normalized scalar wind speed distribution for Cape Camaveral.

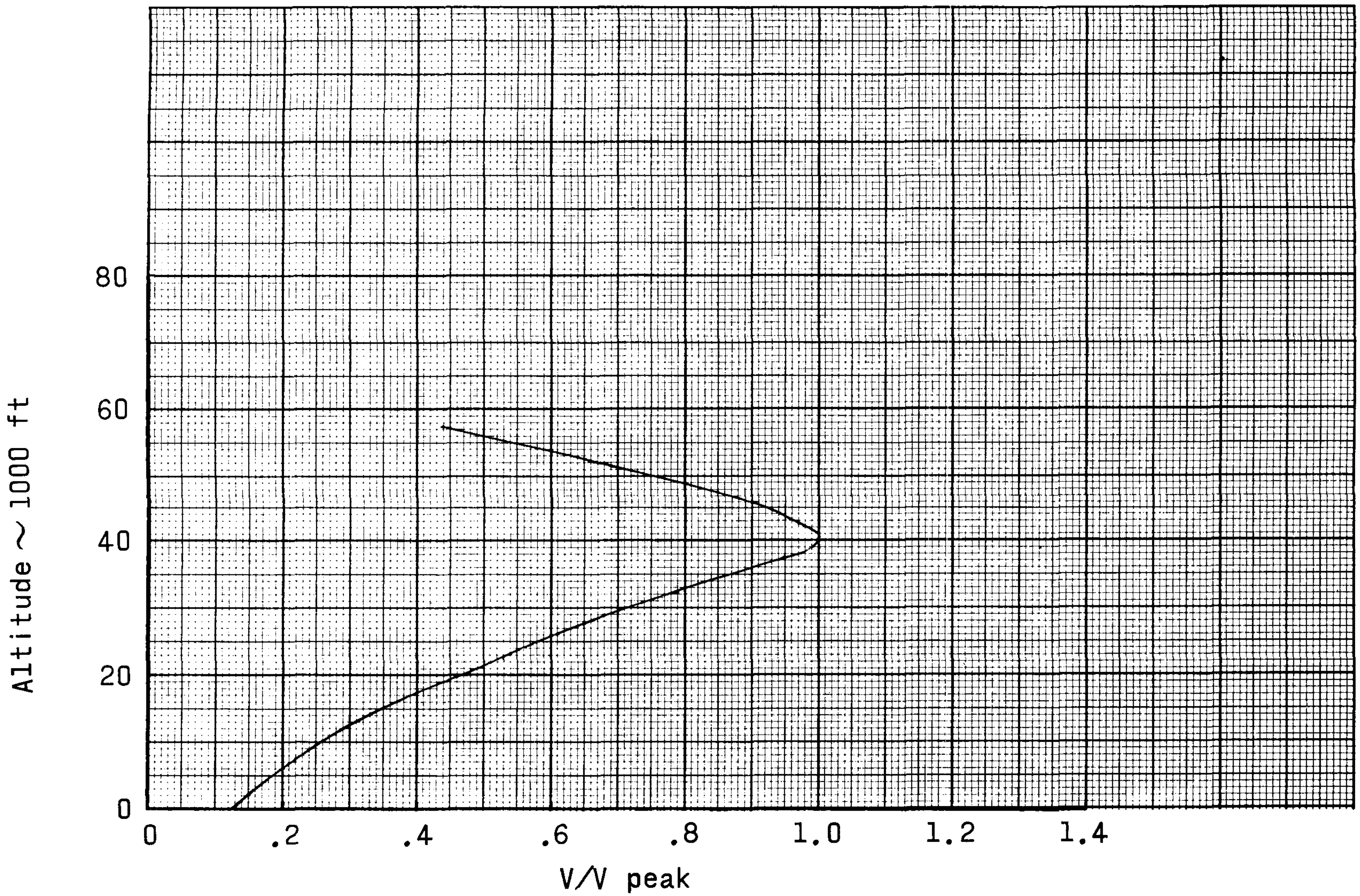

Figure 3.- Selected normalized wind speed profile.

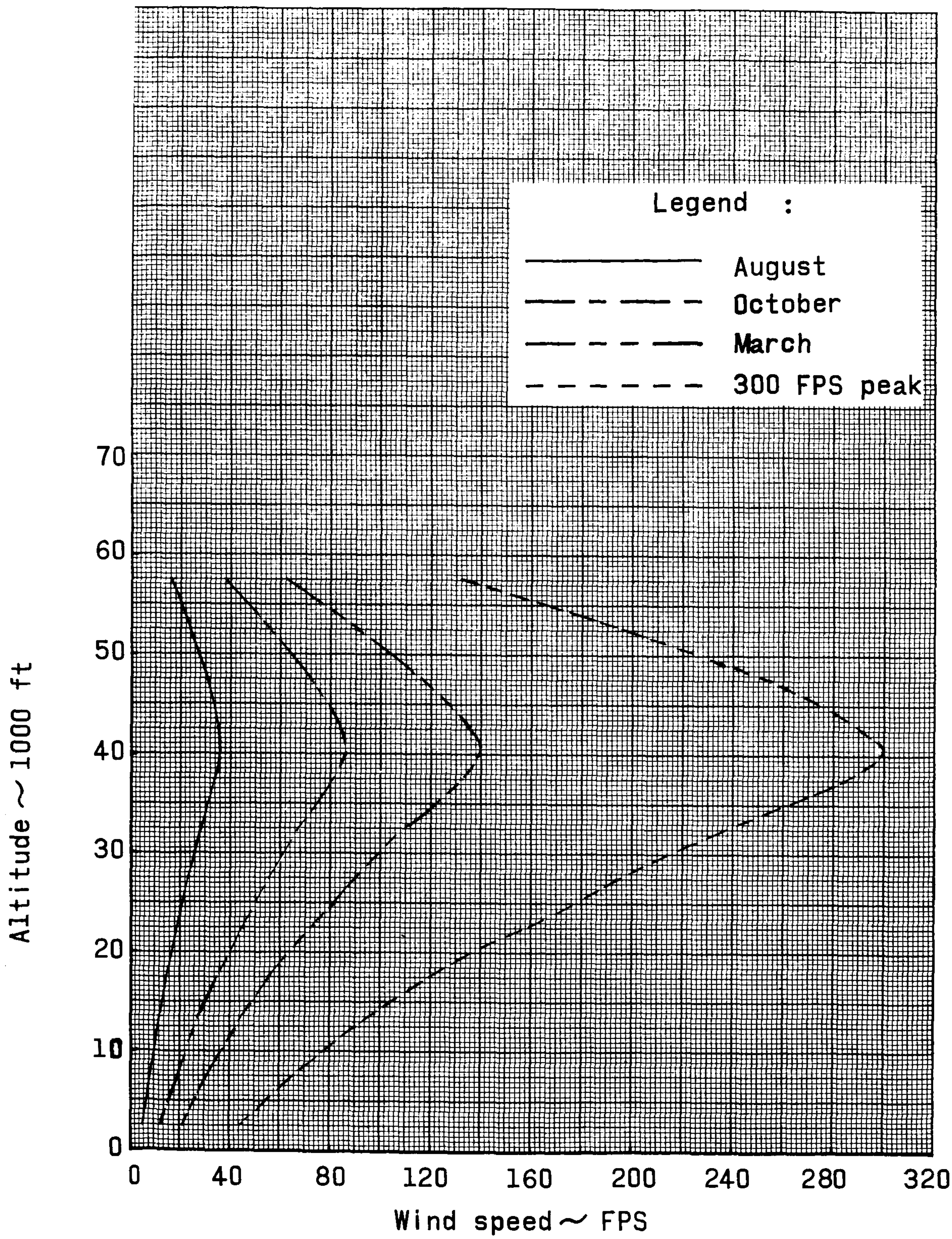

Figure 4.- Wind profiles based on normalized shape.

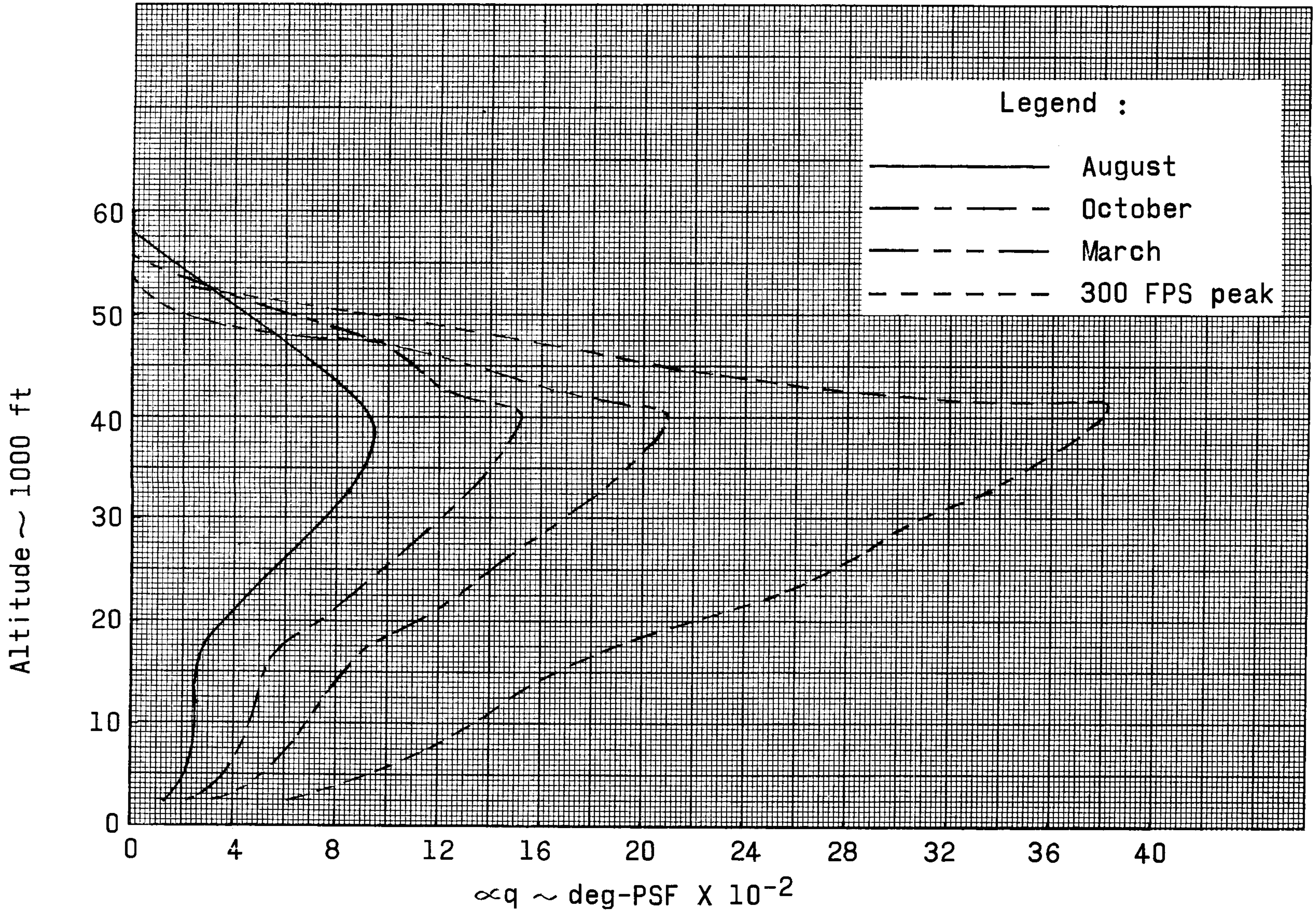

Figure 5.- Vehicle response to selected wind profiles.

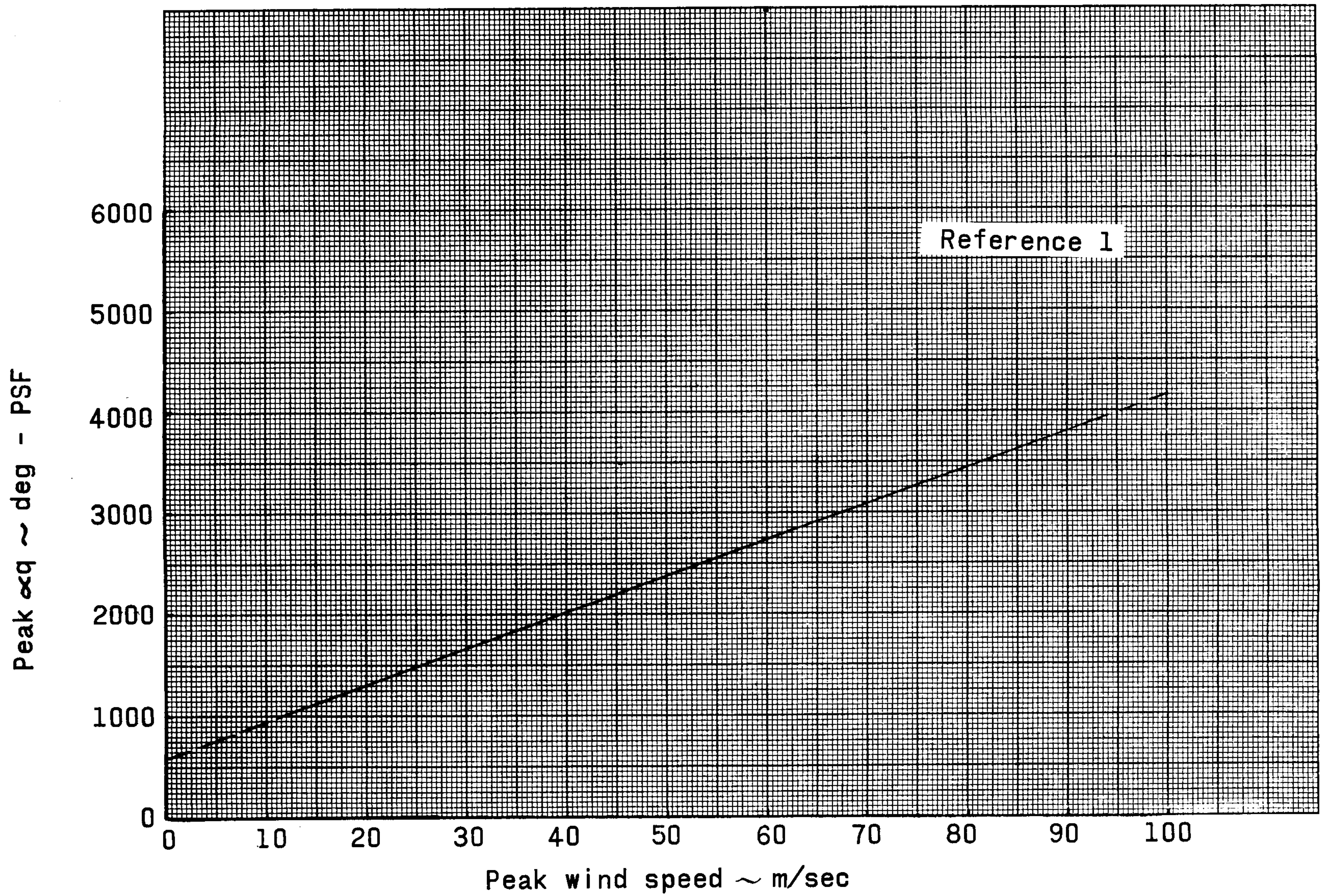

Figure 6.- Peak αq vs peak windspeed.

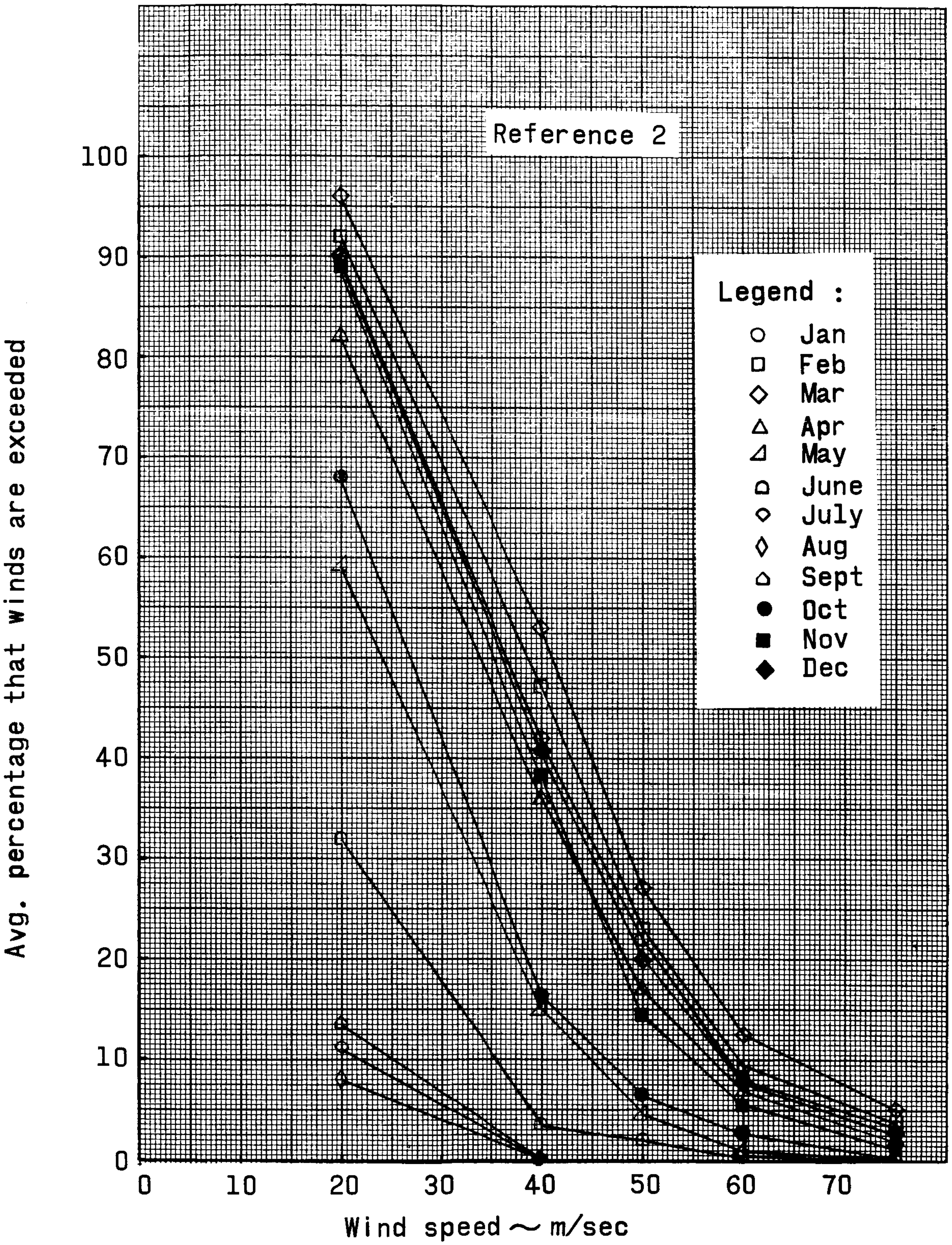

Figure 7.- Wind speed probability for Cape Canaveral in the 10-14 Km. altitude region.